Journal of Management Science Research Review
https://jmsrr.com/index.php/Journal/about

Volume. 4 Issue No. 3 (2025)

Online ISSN: 3006-2047
Print ISSN: 3006-2039

ECONOMIC BARRIERS TO GREEN ENERGY: ADDRESSING POVERTY, INEQUALITY AND SUSTAINABILITY

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Abstract

Renewable energy as one of the solutions to environmental degradation, income inequality, and poverty are essential in the global challenge. This paper examines the connection between consumption of renewable energy and socio-economic factors, like income inequality and poverty, with economic growth, fintech and technology diffusion as control variables. Employing data on 126 countries within 2001 to 2022, the panel econometric analysis to determine the dynamics of renewable energy adoption was carried out using the robust panel econometric methods, such as the System GMM approach and the Driscoll-Kraay regression. The results indicate that the reduction of renewable energy consumption is highly connected to poverty with a coefficient of -0.0329 but there is no statistically significant impact on income inequality. The values of negative coefficient of -0.1152 and -0.1222 indicate economic growth and fintech have a negative influence on renewable energy consumption. Technology diffusion on the other hand has a positive but statistically insignificant relationship. These findings emphasize the need to use specific measures to reduce poverty, coordinate the development of fintech with the objectives of green energy, and promote fair energy transitions. The study contributes to the discourse on sustainable development by presenting practical insights that policymakers can use in

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

their quest to facilitate the use of renewable energy in various socio-economic contexts.

Keywords: Income inequality, renewable consumption, poverty, System GMM method, Driscoll-Kraay regression

Introduction

Sustainable development has become one of the most important concerns of the nations of the world since it has been realized that the way things are being done now in terms of exploitation of resources, economic inequality as well as environmental degradation is threatening the future generation. The UN developed Sustainable Development Goals (SDGs) in 2015 that consist of 17 aims to address poverty, inequality, environmental sustainability, and institution resilience (Barbara, 2020; Fuso Nerini et al., 2018). Among these, poverty and inequalities reduction as well as the enhancement of the environmental quality are essential to attain harmonious and sustainable societies (UN, 2019). Despite the efforts that the world has undertaken, in an endeavor to curb these challenges, income inequality and environmental degradation remain a significant drawback to the realization of sustainable development (Liu et al., 2019). The urgency of discussing the issue of such interrelated concerns is proved by the fact that climate change and inequalities are among the most current global issues that the United Nations identified (UN, 2019).

Global warming, climate change and ecological imbalance have been caused by the increased strain which the environment has faced because of the increasing pressure to satisfy the energy demands through the utilization of fossil fuels. According to the BP Statistical Review of World Energy (2019), fossil fuels use primary energy in the world at the rate of 75 percent, which has resulted in a massive emission of greenhouse gases and reduce energy efficiency. Even though renewable energy is cleaner and more sustainable, the demand in renewable energy should be significantly increased to prevent

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

environmental consequences of fossil fuel addiction (Burke & Stephens, 2018; Bashir et al., 2021). The need to reduce the use of non-renewable sources of energy has always been associated with the increase in CO_2 emissions and environmental degradation and thus there is a need to switch to renewable sources of energy such as biomass, solar, thermal, and wind energy (Pascual et al., 2015; Adedoyin et al., 2021). This transition is not only crucial to SDGs but also needs to be made to address the energy security concerns and price fluctuations of oil caused by fossil fuel addiction.

Poverty and income inequality are the key issues in the renewable energy debate because they have a significant impact on access and use of energy resources. Poverty is not just a lack of income as it also includes lack of access to education, health, basic services and inability to be involved in decision-making processes (UN, 2021b). The elimination of poverty is part of the SDGs, and it is one of three interconnected goals that include poverty alleviation, income equality, and access to modern energy (UN, 2021a). Nevertheless, the global poverty rates are still incredibly high, with 8.5 percent of the world population being in the extreme poverty line, and the COVID-19 pandemic making the situation worse by making another 100 million people fall into poverty (World Bank, 2024). These issues are vital in solving the problem of ensuring equitable energy access and sustainable development.

The issue of income inequality also complicates the process of adopting renewable energy by creating inequality in access to clean energy technology. The richer individuals and communities are better placed to invest in renewable sources of energy such as solar panels and wind turbines, whereas the less privileged population groups have limited access to investment and infrastructure constraints (Sohail et al., 2021; Xu & Ullah, 2023). Besides, the social norms and collective action are affected by income inequality because unequal societies are also characterized by low social cohesion and trust that negatively influences the long-term environmental sensitivity (Uzar &

Online ISSN: 3006-2047
Print ISSN: 3006-2039

Eyuboglu, 2019; Mushta et al., 2020). This association is one of the reasons why the use of non-renewable forms of energy is still on and why renewable forms of energy cannot be used in large quantities.

The purpose of the research paper is to study the links between the consumption of renewable energy, income inequality, and poverty. The study investigates statistics of the 126 countries in the period between 2001 and 2022, and therefore, it is global in scope and the findings can be generalized to other geopolitical realities (Gao et al., 2024; Beldi & Ghazouani, 2024). The findings should be used to develop policy interventions that can assist in the management of socio-economic and environmental concerns to provide a more equitable and sustainable energy transition.

The following sections of this paper are organized as follows: Section 2 provides a theoretical discussion and formulates hypotheses on how income inequality and poverty affect renewable energy consumption. The materials and methods of this research are outlined in Section 3 and the empirical results discussed in Section 4. Lastly, Section 5 concludes by giving the policy implications, limitations, and future research recommendations.

Theoretical Analysis and Hypothesis Formulation

Energy Justice Framework (EJF)

The Energy Justice Framework (EJF) is a theoretical framework that provides a solid basis to the study of the relationship between the consumption of renewable energy and the socio-economic, including income inequality and poverty, and their interaction with the control variables, namely, economic growth, fintech, and technology diffusion. The framework was established in the 21st century by other researchers such as Sovacool, Heffron, McCauley and Goldthau, who emphasized the principles of equity, fairness and inclusion in energy systems (Sovacool et al., 2016). The ethical scope of the EJF is to work on the ethical factors of energy production, distribution and use in support of distributive, procedural and recognition justice in the energy transitions.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

The framework is also aligned with the issue of income inequality since it indicates the disparity of access to energy as a significant barrier to the establishment of equitable renewable energy consumption. Renewable technologies are more affordable to the richer members of society, yet the poorer members of society still rely on the traditional sources of energy which are polluting due to the financial and infrastructural constraints (Day et al., 2016). Such inequality demonstrates the need to take special steps to enable the provision of renewable energy options to the disadvantaged populations and, thereby, remove the problems of distributive justice.

On the same note, poverty is a key component of the Energy Justice Framework. The poverty level limits the economic capacity to adopt renewable energy technology, which is still dependent on fossil energy and causes energy poverty. The framework emphasizes the importance of procedural justice by the means of advancing inclusive policy-making processes in which low-income groups are involved in making decisions about energy transition (Bickerstaff et al., 2013). It also promotes recognition justice, which takes into consideration and addresses special challenges that the poor populations face during renewable energy programs.

In this framework, economic growth, fintech, and technology diffusion are very important enablers. Economic growth will also provide the funds necessary to invest in the renewable energy infrastructure and to subsidize households in low-income categories to provide equality of access. The democratization of renewable energy investments can be achieved with the assistance of fintech platforms by offering new financial instruments, such as microloans and crowdfunding, which can be particularly beneficial to underserved groups (Meiling et al., 2021). Diffusion of technology ensures that renewable energy technologies are widely available and thus cheaper to use by the social-economic groups (Dong et al., 2024).

The EJF also notes the relationship between the variables and consumption of renewable energy. The framework can be employed in the generation of viable

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

information on how to create inclusive and equitable energy systems by integrating the concepts of distributive, procedural, and recognition justice. To illustrate this, the adoption of technology and fintech can be slowed down due to income inequality and poverty, and therefore, the feedback loops are established to perpetuate the current state of inequality in access to renewable energy. Conversely, such socio-economic barriers can be overcome through policies that facilitate renewable energy transitions, thereby contributing to the realization of other sustainability and social equity goals.

Hypothesis Formulation

Income Inequality and Renewable Energy Consumption

The interaction between income inequality and the consumption of renewable energy sources is complex and multidimensional and is a key to understanding and promoting sustainable energy changes. The use, access and cost of renewable energy technologies greatly depends on socio-economic differences. Richer households and communities also tend to have better access to renewable energy sources because they can afford the initial cost of installing solar panels or other green technologies. On the other hand, low-income groups often use traditional, non-renewable sources of energy because of the financial limitations, which leads to the continuity of the carbon-intensive energy sources. This unbalanced access highlights income inequality as one of the possible obstacles to the widespread use of renewable energy (Uzar, 2020; Tan & Uprasen, 2021).

Renewable energy adoption is also influenced by income inequality in the way it allows or denies a certain political and economic system. Greater income inequality is usually associated with a reduction in the public demand to have strong environmental policies because marginalized populations are more concerned with the short-term economic issues than the long-term environmental ones (Baloch & Danish, 2022). Such dynamic may lead to a lack of governmental action to support renewable energy infrastructure and inadequate incentives to invest in green energy, thus hampering the

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

achievement of clean energy transitions. Observations in developing countries, including sub-Saharan Africa and South Asia, show that income inequality is one of the factors that weakens the establishment of inclusive energy systems (Mahalik et al., 2023; Asongu & Odhiambo, 2021).

On the other hand, equitable income distribution has the potential of involving more individuals in society in the process of adopting renewable energy. Green technology adoption is known to be enhanced by policies that lower income inequality, such as progressive taxation and renewable energy subsidies, which also makes green technologies more affordable to the low-income population (Sharma & Rajpurohit, 2022). Also, fair economic systems enable more individuals to subsidize environmental processes, which positively frames the situation within which policies can be implemented and clean energy projects financed by the private sector (McGee & Greiner, 2019).

The relationship between income inequality and the use of renewable energy indicates that sustainable energy systems can change everything. Investments in renewable energy infrastructure are not only able to reduce greenhouse emissions but also create economic prospects particularly in the underdeveloped regions. To illustrate, the renewable energy projects may generate job opportunities in rural areas and low-income populations, which provides an avenue of economic development and reduces income disparity (Mahalik et al., 2023; McGee & Greiner, 2019). In addition, low-income families and households have the opportunity to save their money on energy, as the access to renewable sources is not a considerable expense, which will allow reallocating financial resources to other needs and, therefore, improving general living conditions (Sharma & Rajpurohit, 2022).

The literature also emphasizes that the issue of income inequality needs to be solved to achieve equitable transitions to renewable energy. The research on ASEAN countries proves that the non-equality of the benefits of renewable energy is also strengthened by the non-equality of the high income, which limits its impact on the society (Tan & Uprasen, 2021). Similarly, the studies

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

in OECD countries show that reducing income inequality can maximize the positive effect of renewable energy policies to ensure that their benefits are equitably distributed among the socio-economic classes (Muhammad et al., 2022). Thus, social equity and environmental goals are harmonized to be inclusive and sustainable energy transitions.

The issue of income inequality is a key factor in the consumption of renewable energy, both in terms of adoption and the distribution of green energy technologies. The reduction of income inequalities by implementing specific policies and making investments in the renewable energy infrastructure will facilitate a more inclusive shift toward sustainable energy systems. Incorporation of equity into environmental policy frameworks would allow policymakers to maximize the complementary effects of reducing income inequality and supporting global climate efforts, as part of a sustainable energy future that is just.

H1. Income inequality affects renewable energy consumption.

Poverty and Renewable Energy Consumption

Poverty and renewable energy consumption are intertwined, and such a connection has serious impacts on sustainable development. The poor do not have access to modern energy services, and this is why many poor households have to use traditional sources of energy like biomass that is inefficient and environmentally degrading. This energy poverty has created a cycle of economic deprivation and environmental degradation that constrains economic development and the ability to adopt renewable energy technology (Day et al., 2016). The solution to this problem should be multidimensional, where the socio-economic obstacles to the accessibility and utilization of renewable energy sources should be taken into consideration.

The theoretical framework assumes that poverty has both economic and social effects on the consumption of renewable energy. Economically, low-income communities also have problems with affordability, because the initial cost of renewable energy sources, including solar panels or wind

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

turbines, is usually too expensive (Teixeira et al., 2024). Socially, there is a lack of proper knowledge and education on the usefulness of renewable energy which discourages its use. Such barriers dictate that specific interventions (subsidies and microfinance) are necessary to increase accessibility by reducing the affordability gap (Cheng et al., 2021).

On the other hand, renewable energy can be used to ease poverty through cost effectiveness in energy and job creation within the green industries. As an example, mini-grids and solar home systems can be decentralized renewable energy systems that will provide affordable and reliable energy access to the rural and underserved populations. Such a transition not only enhances the standards of living but also allows economic activities thus promoting socio-economic development (Filippidis et al., 2021). Research conducted in developing nations has revealed that rural electrification via renewable energy can greatly decrease the level of poverty by improving educational achievement and access to health care (Simionescu et al., 2024).

The relationship between poverty and renewable energy consumption is bidirectional and empirical evidence has supported this fact. Studies in sub-Saharan Africa show that the regions that have less poverty have a higher rate of renewable energy adoption because of the higher purchasing power and the support of the government (Nguyen & Su, 2021). Conversely, poverty rates limit the development of renewable energy markets, and thus, policies that combine poverty-reduction objectives with energy-transition ones are needed (Fernando et al., 2022).

The framework emphasizes the importance of having policies that are inclusive and which touch on energy and economic poverty. Government subsidies on renewable energy technologies, tax incentives on green investments and community-based energy projects can accelerate the rate of renewable energy adoption by the low-income population. Moreover, foreign financial assistance and the idea of the collaboration of both the state and the

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

business are essential to the development of renewable energy in developing countries, hence connecting economic prosperity with environmental sustainability (Priesmann et al., 2022).

The relationship between poverty and renewable energy consumption is a critical issue to understand in order to develop effective policies that foster energy transitions towards sustainability, and at the same time, reduce socio-economic disparities. The combination of poverty reduction and renewable energy projects will help the policymakers to accomplish two objectives of environmental conservation and socio-economic upliftment.

H2. Poverty affects renewable energy consumption.

Data and estimation Methodology

The proposed study examines the association between renewable energy usage, income inequality, and poverty, with other control variables being economic growth, fintech, and technology diffusion. The variables were selected in a careful manner to reflect the socio-economic and technological factors that can impact renewable energy adoption. The dependent variable is renewable energy consumption, and the independent variables are income inequality and poverty. The control variables are economic growth, fintech, and diffusion of technology which are key aspects of energy transitions.

Description and Sources of Data

All the data of the variables were obtained on the World Development Indicators (WDI) database, which is characterized by the high quality of the data, its comprehensiveness, and international standardization of economic and development indicators (Table 1). The data range is 2001-2022 and consists of 126 countries depending on the availability of the data. The wide range of time and sample selection provides the analysis with both temporal trends and cross-national differences, which is a strong factor in determining the dynamics of renewable energy adoption and socio-economic determinants.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

Table 1: Data Description

Variable Name	Acronyms	Proxy	Data Source	Period
Renewable Energy Consumption	REC	*"Renewable Energy Consumption (% of Total Energy Consumption)"*	WDI	2001-2022
Income Inequality	II	*"GINI Index"*	WDI	2001-2022
Poverty	POV	*"Poverty Headcount Ratio"*	WDI	2001-2022
Economic Growth Sustainability	EGS	*"Annual Growth Rate of Real GDP per capita (%)"*	WDI	2001-2022
Financial Technology	FT	*"Automated Teller Machines (ATMs) (Per 100,000 Adults)"*	WDI	2001-2022
Technology Diffusion	TD	*"Individuals Using the Internet (% of Population)"*	WDI	2001-2022

Preprocessing analysis of the data in STATA 18.5 program was conducted. STATA is acknowledged to be strong in statistical modeling and automated reporting and was used to deal with missing values, outlier identification, and variable transformation to address problems such as heteroscedasticity and

Journal of Management Science Research Review
https://jmsrr.com/index.php/Journal/about

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

skewness. According to the established practice, natural logarithm transformations were applied to all the variables. This log-linear model overcomes the problem of data distribution by providing a more constant variance between observations and thus enhancing the fit of the model in multivariate regression analysis. The study methodology is also reinforced by the use of a positivist research paradigm. It is an objectivity and empirical based paradigm that allows the evaluation of causal links based on quantitative methodologies (Diener et al., 2000).

Econometric Model and Econometric Methodology

Econometric Model Construction

The econometric model formulated in this study focuses on the log-linear model to analyze the relation between renewable energy consumption (REC) as a dependent variable and income inequality (II), poverty (POV) as independent variables and control variables (economic growth sustainability, fintech, and technology diffusion). The model is given as follows:

$$ln(REC_{it})=\alpha+\beta_1 \; ln(II_{it})+\beta_2 \; ln(POV_{it})+\beta_3 \; ln(EGS_{it})+\beta_4 \; ln(FT_{it}) +\beta_5 \; ln(TD_{it})+e_{it} \ldots\ldots\ldots\ldots\ldots\ldots(i)$$

Where $ln(REC_{it})$ represents the natural log of renewable energy consumption for country i at time t. $ln(II_{it})$ and $ln(POV_{it})$ are the natural logs of II and poverty, respectively. $ln(EGS_{it})$, $ln(FT_{it})$, and $ln(TD_{it})$ denote the natural logs of economic growth sustainability, fintech, and technology diffusion. α is the constant term, β_1 to β_5 are coefficients for explanatory variables, and e_{it} is the error term.

This log-linear model estimates the elasticities of renewable energy consumption relative to the explanatory variables and are thus interpretable measures of percent change in the dependent variable.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

Econometric Methodology

A thorough econometric approach was embraced in order to achieve sound and stable results. The paper used various diagnostic and inferential tests to test the model and to reduce econometric problems.

Descriptive statistics were computed to provide a summary of the measures of central tendency, dispersion, and distribution characteristics of the variables. These statistics gave the first idea about the structure of the data, and they pointed out the possible anomalies. Correlation analysis was done to check the strength and direction of relationships between variables, which would give preliminary information about possible multicollinearity. Multicollinearity was checked by means of VIF tests. A VIF of less than 10 indicated that there was no excessive correlation between independent variables, which enhanced the validity of regression estimates.

The Pesaran CD test was adopted to test the cross-sectional dependence since the data was panel. This test takes into consideration the fact that countries are connected, which can affect the consumption patterns of renewable energy because of the global energy policies and technologies. To make sure that the variables are stationary, panel unit root tests were performed. Non-stationary variables were different or transformed in order to obtain stationarity. The Westerlund cointegration test also evaluated whether there were long-run relationships between the variables, and this aspect proved to be valid in the model structure as time passed. The Wald test was used to determine whether the explanatory variables were significant as a group and the result indicated that the model was overall significant.

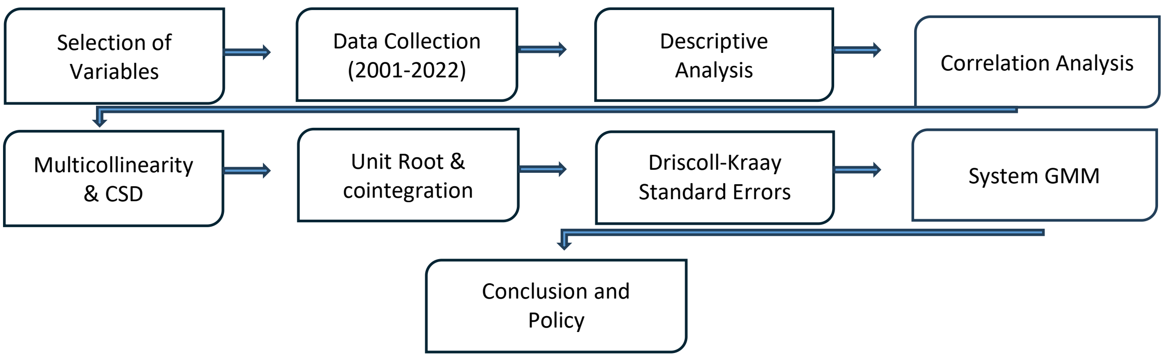
The panel data considered heteroscedasticity and autocorrelation, and therefore, the Driscoll-Kraay standard error estimator was used. This is a powerful technique that corrects the dependence of cross-sections of the standard errors, which improves the validity of hypothesis testing. The System Generalized Method of Moments (System GMM) was used to deal with the issues of endogeneity and dynamic panel bias. In panel data where

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

endogeneity may be a problem, this estimator is more efficient and consistent than the lagged levels and differences are used as instruments.

The approach to methodology combines modern econometric tools to reduce bias, increase accuracy, and offer reliable information on factors that influence consumption of renewable energy. The study provides a complete picture by integrating intense testing with log-linear specification, which contributes to the knowledge about socio-economic determinants of renewable energy transitions. The findings are also insensitive to the inclusion of control variables that eliminate the chances that the findings are being influenced by omitted variables. The application of these methodologies, strong standard errors, and endogeneity controls makes the findings reliable and their policy implications.

Fig 1: Flow of the Empirical Analysis



Results

Descriptives

The descriptive analysis provides a statistical summary of the variables under investigation, offering insights into their distribution, central tendencies, and variability (Table 2). Renewable energy consumption (REC), the dependent variable, has a mean value of approximately 34.84, with a standard deviation of 27.86, indicating significant variation in renewable energy adoption across the 2,772 observations. The minimum value of REC is 0.01, while the maximum reaches 95.36, highlighting disparities among nations, with some

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

heavily reliant on renewable sources while others exhibit minimal consumption.

Table 2 Descriptives

Variable	Obs	Mean	Std. dev.	Min	Max
REC	2,772	34.83696	27.86419	.01	95.36
II	2,772	38.00047	8.157118	23.2	64.8
POV	2,772	13.3473	19.88206	.01	80.71
EGS	2,772	37.52357	4.491904	.796136	70.83387
FT	2,772	45.50607	48.06959	.01	288.6
TD	2,772	40.13316	31.66008	.01	99.69702

Income inequality, an independent variable, has a mean value of 38.00 and a standard deviation of 8.15, suggesting moderate variability. The minimum value of 23.2 and the maximum value of 64.8 imply that some countries exhibit low-income inequality, while others face substantial inequality challenges. Poverty, another key independent variable, has a mean of 13.35 with a high standard deviation of 19.88. The range, spanning from 0.01 to 80.71, indicates that poverty levels vary drastically across nations, with certain regions experiencing extreme poverty while others have nearly eradicated it.

Economic growth has a mean of 37.52 and standard deviation of 4.49, which is relatively low implying that the level of economic growth is less spread out than other variables. Fintech has a high mean of 45.51 and a large standard deviation of 48.07 indicating a lot of variability. Lastly, the mean of technology diffusion is 40.13 and standard deviation is 31.66. Such a broad range is indicative of a large disparity in the spread of technology among nations and of unequal advancement in technological infrastructure.

Correlation

The correlation matrix gives information on the pair wise relationship between the variables in log form. REC is the dependent variable that has significant correlations with the independent variables and control variables.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

According to Table 3, there is also a positive relationship between lnII and lnREC, having a coefficient value of 0.2924, which indicates that the higher the levels of II, the greater the consumption of renewable energy. This correlation can be interpreted as an indication that countries with income inequalities may still invest in renewable energy projects under some circumstances which may be due to policies or technological developments that support energy transitions despite inequality.

lnPOV exhibits a stronger positive correlation with lnREC, with a coefficient of 0.5692, indicating that higher poverty levels are associated with higher renewable energy consumption. This seemingly counterintuitive result could be explained by the reliance of poorer communities on decentralized renewable energy solutions, such as solar and biomass, due to limited access to centralized fossil-fuel-based energy systems.

Table 3 Correlation Analysis

	lnREC	lnII	lnPOV	lnEGS	lnFT	lnTD
lnREC	1.0000					
lnII	0.2924	1.0000				
lnPOV	0.5692	0.6017	1.0000			
lnEGS	-0.0084	-0.0019	0.0514	1.0000		
lnFT	-0.5279	-0.2233	-0.6914	-0.0727	1.0000	
lnTD	-0.3986	-0.3062	-0.6540	-0.0647	0.8127	1.0000

The lnEGS has a very weak negative correlation with lnREC, with a coefficient of -0.0084, which shows that there is no significant linear relationship between economic growth and renewable energy consumption. The correlation between lnFT and lnREC is moderate and negative, the coefficient is -0.5279, which means that the higher the degree of fintech development, the lower the consumption of renewable energy. Such an outcome can be explained by the idea that countries with developed financial technologies tend to focus on industrial and economic areas that are traditionally

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

dependent on the conventional sources of energy at the beginning of their development.

It can also be seen that lnTD has a negative correlation to lnREC, that is, the coefficient is -0.3986 and this indicates that more technological dissemination is linked to lower renewable energy usage. This finding may be attributed to the fact that technological adoption is still in its early phase in the countries where fossil-fuel-based technologies are still the dominant ones or where renewable energy innovation has not been able to acquire a lot of popularity as yet. In general, the correlation outcomes demonstrate the combination of positive and negative associations, which implies that the II and poverty are strongly associated with the consumption of renewable energy, whereas fintech and technology diffusion are negatively connected.

Multicollinearity

The outcomes of the test of multicollinearity, as measured by the Variance Inflation Factor (VIF), are valuable to gain insights regarding the extent of the linear correlation among independent variables in the model. A VIF value above 10 usually suggests that there is a problem of multicollinearity that may affect the reliability of the regression estimates as they inflate the standard errors. The average VIF value of 2.59 indicates that there is moderate multicollinearity among the variables, which is well below the acceptable limits and therefore the results of the regression analysis will be very solid and will not be affected by the collinearity problem.

Among the individual variables, lnFT shows the highest VIF value of 3.78, followed closely by lnPOV at 3.25 and lnTD at 3.13. While these values do not signal severe multicollinearity, they suggest some degree of correlation between these variables, which aligns with the earlier findings in the correlation matrix, where fintech and technology diffusion exhibited a strong positive correlation (0.8127). Similarly, poverty's correlation with both fintech and technology diffusion likely contributes to its moderately high VIF value.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

Table 4 Multicollinearity

Variable	VIF	1/VIF
lnFT	3.78	0.264435
lnPOV	3.25	0.307904
lnTD	3.13	0.319544
lnII	1.79	0.560018
lnEGS	1.01	0.993922
Mean VIF	2.59	

The VIF for lnII is 1.79, indicating a low level of multicollinearity, further confirming its independence relative to the other explanatory variables. Lastly, lnEGS exhibits the lowest VIF value at 1.01, suggesting no multicollinearity concerns for this variable. In conclusion, while there is a moderate association between fintech, poverty, and technology diffusion, the VIF values remain below the critical threshold of 10.

Cross Sectional Dependence Test

The findings of the Cross-Sectional Dependence (CD) test demonstrate that cross-sectional dependence is significant across all variables since the p-value is 0.000 in each case. The p-value of less than 0.05 leads to a conclusion that the null hypothesis of no cross-sectional dependence is rejected strongly.

Table 5 Cross Sectional Dependence Test

Variable	CD-test	p-value	Average joint T	mean ρ	mean abs(ρ)
lnREC	+ 4.784	0.000	22.00	+ 0.01	0.59
lnII	+ 54.751	0.000	22.00	+ 0.13	0.47
lnPOV	+ 136.61	0.000	22.00	+ 0.33	0.50
lnEGS	+ 152.24	0.000	22.00	+ 0.37	0.40
lnFT	+ 204.144	0.000	22.00	+ 0.49	0.71
lnTD	+ 384.084	0.000	22.00	+ 0.92	0.92

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

All the variables have positive and significant CD-test statistics with different magnitudes. As an illustration, lnTD has the largest CD-test statistic of +384.084 and a mean correlation (ρ) of +0.92, which means that there is a very strong dependence between cross-sections. On the same note, lnFT is also highly cross-sectionally dependent with the mean correlation of +0.49 and a CD-test value of +204.144. This implies that fintech and diffusion of technology have common patterns or external shocks among countries which could be as a result of globalization or common technological trends.

Other variables, such as lnPOV and lnEGS, also display significant cross-sectional dependence, with mean correlations (ρ) of +0.33 and +0.37, respectively. Meanwhile, lnII shows moderate cross-sectional dependence with a mean correlation of +0.13. lnREC has a lower mean correlation of +0.01, but its CD-test statistics (+4.784) and p-value still confirm significant dependence.

Overall, the findings suggest that the variables exhibit interconnectedness across countries, likely due to shared global economic, technological, or environmental factors. This highlights the importance of using econometric techniques, such as models robust to cross-sectional dependence (e.g., Driscoll-Kraay standard errors or System GMM), to ensure accurate and unbiased results in the regression analysis.

(CADF unit root test) 1st dif.

The results of the CADF unit root test at the first difference confirm the stationarity properties of the variables under investigation. Initially, at level form, lnREC fails to reject the null hypothesis of non-stationarity. However, when differenced once (d.lnREC), the variable becomes stationary, with a t-bar value of -4.281 and a p-value of 0.000, strongly rejecting the null hypothesis.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

Table 6 CADF unit root test

Variables	t-bar	cv10	cv5	cv1	Z[t-bar]	P-value
lnREC	-1.852	-2.000	-2.050	-2.140	-1.066	0.143
d.lnREC	-4.281	-2.000	-2.050	-2.140	-29.177	0.000
lnII	-2.125	-2.000	-2.050	-2.140	-4.229	0.000
lnPOV	-2.337	-2.000	-2.050	-2.140	-6.678	0.000
lnEGS	-3.044	-2.000	-2.050	-2.140	-14.855	0.000
lnFT	-2.555	-2.000	-2.050	-2.140	-9.202	0.000
lnTD	-2.804	-2.000	-2.050	-2.140	-12.077	0.000

All other variables, including lnII, lnPOV, lnEGS, lnFT, and lnTD, are stationary at their level forms. This is evidenced by their t-bar values, which are all lower than the 1%, 5%, and 10% critical values, and their respective p-values of 0.000, confirming the rejection of the null hypothesis of non-stationarity. For example, lnII has a t-bar value of -2.125, and lnEGS has a t-bar of -3.044, both significant at the 1% level. In summary, the results demonstrate that all variables are either stationary at level or become stationary after the first difference (in the case of lnREC).

Cointegration Test

The results of the Westerlund test for cointegration provide strong evidence for the presence of a long-run relationship between the variables under consideration. The null hypothesis (H_0) of no cointegration is clearly rejected, as indicated by the Variance Ratio statistic of 4.1071 and a highly significant p-value of 0.0000. This suggests that, across the 126 panels (countries) and 22 time periods (2001–2022), at least some panels exhibit cointegration between REC, II, POV, and the control variables (EGS, FT, and TD).

Table 7 Westerlund Test for Cointegration

	Statistic	p-value
Variance ratio	4.1071	0.0000

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

These results confirm that the variables share a stable and long-term equilibrium relationship, making it appropriate to proceed with cointegration-based regression techniques, such as System GMM or Driscoll-Kraay standard errors, to capture both short- and long-run dynamics in the model.

Wald Test for Joint Significance

Table 8 Wald Test for Joint Significance

(1) lnII = 0
(2) lnPOV = 0
(3) lnEGS = 0
(4) lnFT = 0
(5) lnTD = 0

F(5, 2766) = 331.14

Prob > F = 0.0000

The Wald test for joint significance evaluates whether the specified independent variables, including II, POV, and other controls (EGS, FT, TD), collectively influence REC. The test statistic, F(5, 2766) = 331.14, with a corresponding p-value of 0.0000, indicates that the null hypothesis—that all coefficients of the specified variables are simultaneously equal to zero—can be strongly rejected at any conventional level of significance. This outcome implies that II, POV, and the included control variables jointly have a statistically significant effect on renewable energy consumption.

Slope Homogeneity Test

The results from the Slope Homogeneity Test using the Mean Group (MG) estimation provide insight into the relationship between REC and its determinants, specifically II, POV, and the control variables. The Wald chi-squared statistic is 41.97 with a p-value of 0.0000, indicating strong evidence against the null hypothesis of slope homogeneity across the panel, suggesting that the coefficients differ significantly across units in the dataset.

The individual coefficients reveal mixed effects. The coefficient for lnII is negative but insignificant (coefficient = -0.121, p>0.694), indicating that II

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

does not have a statistically significant effect on REC in this estimation. In contrast, POV has a positive and statistically significant coefficient (0.0497, p = 0.026), suggesting that higher poverty levels are associated with an increase in REC, albeit with a relatively small effect size.

Table 9 Slope Homogeneity Test

lnREC	Coefficient	Std. err.	Z	P>z	[95% conf.	interval]
lnII	-.121138	.307418	-0.39	0.694	-.7236663	.4813904
lnPOV	.0497339	.0223281	2.23	0.026	.0059716	.0934962
lnEGS	-.1243864	.0336051	-3.70	0.000	-.1902511	-.0585217
lnFT	-.020177	.0936173	-0.22	0.829	-.2036635	.1633095
lnTD	.2087923	.0494339	4.22	0.000	.1119037	.3056809
_cons	2.9907	1.156478	2.59	0.010	.7240443	5.257356

Wald chi2(5) = 41.97 Prob > chi2 = 0.0000

Root Mean Squared Error (sigma): 0.1740

Among the control variables, lnEGS demonstrates a significant negative impact (-0.124, p=0.000), indicating that EGS tends to reduce REC, possibly reflecting a shift towards non-renewable energy sources during growth phases. lnTD exhibits a significant and positive relationship (0.208, p=0.000), suggesting that advancements in TD contribute positively to REC. However, lnFT has an insignificant coefficient (-0.020177, p=0.829), showing no measurable effect on REC in this context.

The constant term is significant (p=0.010), indicating the baseline level of REC when all explanatory variables are held constant. The Root Mean Squared Error (RMSE) of 0.1740 reflects the model's overall fit.

System GMM

The System GMM dynamic panel-data estimation provides critical insights into the relationship between lnREC and its determinants, including II, POV, and control variables. The lagged dependent variable (lnREC L1) is positive and highly significant (β=0.8566, p=0.000), suggesting strong persistence in

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

REC over time. This indicates that past levels of REC have a substantial influence on its current levels, highlighting inertia in renewable energy adoption patterns.

lnII has a significant and negative effect on REC ($\beta = -1.005$, $p = 0.003$), indicating that higher II reduces REC. This result underscores the potential role of unequal income distribution in limiting investments or adoption of renewable energy technologies, possibly due to disparities in access to resources or affordability constraints. Conversely, lnPOV has a positive and significant impact ($\beta = 0.0881$, $p = 0.004$), suggesting that higher poverty levels are associated with increased REC. This counterintuitive result may reflect reliance on renewable energy sources, such as biomass or other traditional renewables, in regions with higher poverty rates.

Table 10 System GMM

Number of instruments = 26 Obs per group: min = 21
F(6, 125) = 5171.30 avg = 21.00
Prob > F = 0.000 max = 21

lnREC	Corrected Coefficient	std. err.	T	P>t	95% conf.	interval
lnREC						
L1.	.8565622	.0678294	12.63	0.000	.7223193	.9908051
lnII	-1.005023	.3370002	-2.98	0.003	-1.671988	-.3380574
lnPOV	.0880771	.03027	2.91	0.004	.028169	.1479853
lnEGS	-.133692	.0279839	-4.78	0.000	-.1890756	-.0783084
lnFT	.0206948	.0255074	0.81	0.419	-.0297876	.0711772
lnTD	-.0012548	.0203287	-0.06	0.951	-.0414878	.0389783
_cons	4.469645	1.302083	3.43	0.001	1.892662	7.046629

Arellano-Bond test for AR(1) in first differences: z = -4.35 Pr > z = 0.000
Arellano-Bond test for AR(2) in first differences: z = -1.37 Pr > z = 0.171
Sargan test of overid. restrictions: chi2(19) = 60.86 Prob > chi2 = 0.000

Hansen test of overid. restrictions: chi2(19) = 22.28 Prob > chi2 = 0.271
Difference-in-Hansen tests of exogeneity of instrument subsets:
GMM instruments for levels
Hansen test excluding group: chi2(18) = 21.28 Prob > chi2 = 0.266
Difference (null H = exogenous): chi2(1) = 1.00 Prob > chi2 = 0.317
iv(lnPOV lnEGS lnFT lnTD, eq(level))
Hansen test excluding group: chi2(15) = 14.93 Prob > chi2 = 0.457
Difference (null H = exogenous): chi2(4) = 7.35 Prob > chi2 = 0.118

Among the control variables, lnEGS has a significant and negative coefficient ($\beta = -0.1337$, $p = 0.000$), indicating that higher EGS reduces REC. This result may reflect an increased reliance on non-renewable energy sources during periods of economic expansion. lnFT and lnTD both exhibits statistically insignificant effects on REC ($p = 0.419$ and $p = 0.951$, respectively), suggesting that their roles may not be direct or significant in this context.

The diagnostic tests validate the robustness of the model. The Arellano-Bond test for AR(1) shows significant first-order serial correlation ($p = 0.000$), which is expected, while the AR(2) test confirms no second-order serial correlation ($p = 0.171$), ensuring model consistency. The Hansen test for overidentifying restrictions yields a p-value of 0.271, supporting the validity of the instruments used in the model. Additionally, the Difference-in-Hansen tests confirm the exogeneity of the instrument subsets, further reinforcing the reliability of the estimation.

Driscoll and Kraay (1998) Regression

The results of the Driscoll and Kraay (1998) regression provide insights into the relationships between REC and the independent variables as well as the control variables, while accounting for heteroscedasticity, autocorrelation, and cross-sectional dependence. The overall F-statistic ($F(5, 21) = 16.93$) is statistically significant with a p-value of 0.0000, indicating that the model collectively explains variation in renewable energy consumption. However, the within R-squared value of 0.0261 suggests that the explanatory variables

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

account for a relatively small proportion of the variance in renewable energy consumption within countries over time.

Table 11 Driscoll and Kraay (1998) Regression

Number of obs = 2772 F(5, 21) = 16.93
Prob > F = 0.0000 within R-squared = 0.0261

lnREC	Drisc/Kraay Coefficient	std. err.	T	P>t	95% conf.	interval
lnII	.0164443	.0994729	0.17	0.870	-.190421	.2233096
lnPOV	-.0329578	.0125533	-2.63	0.016	-.0590639	-.0068517
lnEGS	-.1152387	.0946788	-1.22	0.237	-.312134	.0816566
lnFT	-.1222116	.0337374	-3.62	0.002	-.1923724	-.0520508
lnTD	.0434075	.0284763	1.52	0.142	-.0158122	.1026273
_cons	3.705428	.435381	8.51	0.000	2.800004	4.610853

The coefficient for lnII is 0.0164 but is not statistically significant (p = 0.870). This indicates that income inequality does not have a significant direct effect on renewable energy consumption. The coefficient for lnPOV is -0.0330, and it is statistically significant (p = 0.016). This suggests that higher levels of poverty are associated with lower renewable energy consumption. The negative relationship highlights that poverty restricts access to renewable energy technologies, possibly due to financial and infrastructural barriers.

The coefficient for lnEGS is -0.1152, but it is not statistically significant (p = 0.237). This suggests that EGS does not show a clear direct association with REC. The coefficient for lnFT is -0.1222, and it is statistically significant (p = 0.002). This negative relationship indicates that higher levels of fintech adoption are associated with reduced REC. This counterintuitive result might reflect an initial focus of fintech development on industries and sectors that are less reliant on renewable energy.

The coefficient for lnTD is 0.0434, but it is not statistically significant (p = 0.142). This implies that the impact of TD on REC is unclear and may vary

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

across countries. The constant term is statistically significant (p = 0.000) with a coefficient of 3.7054, indicating the base level of REC when all independent variables are held constant.

These findings suggest that targeted poverty reduction strategies and a more focused alignment of fintech innovations with renewable energy initiatives may be necessary to foster sustainable energy transitions.

Discussion and Conclusions

Discussion

The discussion provides valuable information about the factors that influence the REC and what they mean to sustainable energy transitions. The results of the correlation analysis point out significant relationships between the independent variables and REC. The positive relationship between II and REC indicates that in some cases, the countries with greater II invest in renewable energy projects. This observation is consistent with the previous studies that government policies in unequal societies can motivate renewable energy investment due to energy poverty and political compulsions (Jakob et al., 2014).

The adverse correlation between FT and REC is an indication of the possible mismatch between the development of fintech and renewable energy projects. Since fintech is likely to be used in industries that have a strong dependence on fossil fuels, these findings underline the importance of refocusing fintech investments towards green energy goals (Campbell-Verduyn, 2017). This is also supported by the moderate negative relationship between TD and REC, which implies that initial technological adoption might still be more beneficial to the traditional energy systems rather than the renewables, especially in the industrializing economies.

These insights are further enhanced by the results of System GMM that take into account the time dynamics of REC. The continued adoption of renewable energy indicates the importance of path dependency, which means that the earlier investments and policies determine the future adoption rates.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

This observation highlights the significance of policy-based activities at an early and long-term stage to entrench renewable energy sources in the national energy sectors (Bhattacharyya, 2006). The fact that the negative impact of income inequality on REC is significant, proves that unequal income distribution suppresses the growth of renewable energy, probably because marginalized groups lack access to funding and technologies (Aklin & Urpelainen, 2018). On the other hand, poverty has a positive correlation with REC which could be attributed to the fact that the poor communities are dependent on decentralized renewable energy sources such as solar and biomass because they cannot access the traditional grid energy system.

The Driscoll-Kraay findings provide additional context as they take into consideration cross-sectional dependence and heteroskedasticity. It is interesting to note that II and TD do not show any significant effect on REC, which indicates that there is a difference in their impact on different socio-economic and technological environments. Nonetheless, the strong negative impact of FT on REC implies that the current fintech developments are not sufficiently designed to foster renewable energy transitions. This supports the idea of bringing in green finance tools to fintech systems, including crowdfunding of renewable projects or green bonds (Nassiry, 2018).

Overall, the findings confirm the suggestion of a complex interdependence between the socio-economic factors and the adoption of renewable energy. Even though the problem of income inequality and the incorrect focus of fintech appear as the barriers, poverty and investments in renewable energy are the opportunities to improve things. To overcome these problems and accelerate the processes of sustainable energy transitions, the policymakers should focus on the redistributive policy, green fintech projects, and fair technology distribution.

Implications

The insights gained through the results of this study provide important findings on the strategies and policies that should be adopted to bring about

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

sustainable energy transitions. The research offers practical recommendations on how to attain sustainable energy transitions by discussing the complex interconnections between renewable energy use, II, and POV as well as enabling conditions like fintech and the diffusion of technologies.

At the governmental level, the findings highlight the need to introduce specific policies that can fill the socio-economic divide in order to support renewable energy implementation. This negative relationship between poverty and consumption of renewable energy is very strong which shows that there is need to make available financial support systems, like subsidies, micro finance schemes, and community-based energy projects to make available renewable technologies to underprivileged groups. Redistributive policies should also be a priority to governments in order to lower II because fair distribution of income leads to the support of green energy projects within society. The use of green finance mechanisms within the national financial systems, including renewable energy investments tax incentives and green bonds issuing, can also enhance the mobilization of funds into clean energy development. The policymakers should also respond to the noted mismatch between fintech growth and renewable energy by rewarding green fintech innovations, including crowdfunding platforms of renewable energy initiatives.

In terms of academic research, the study can add to the existing literature on the socio-economic drivers of renewable energy transitions, and it empirically confirms the effect of II and poverty. This study lays down new pathways of research to examine how socio-economic differences affect renewable energy adoption, especially among the developing regions. Researchers can also examine the synergy between TD and REC with specific attention paid to the situations where technological innovations promote the use of fossil fuel-based energy over renewable energy. The study also underscores the importance of interdisciplinary research methods that combine the knowledge of energy justice, economic development, and

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

technology innovation to come up with holistic approaches to comprehending energy transitions.

The international implication of the findings is the global efforts to attain the Sustainable Development Goals (SDGs) especially Goal 7 (Affordable and Clean Energy) and Goal 10 (Reduced Inequalities). International organizations and multilateral agencies must focus on investing in renewable energy infrastructures in low-income and high-inequality countries, so that the global energy transitions are inclusive and equitable. The findings also indicate the significance of international collaboration in enhancing the diffusion of technology and financial innovation that is aligned to the renewable energy requirements. Joint efforts, like knowledge sharing websites and capacity building, can assist nations in embracing best practices to align socio-economic development with renewable energy goals.

Future Directions

Future studies on the issue of renewable energy consumption and poverty as well as income inequality need to include other factors including the stringency of environmental policy, awareness of people, and social education on renewable energy. The further development of the moderated relationships (including the institutional quality or international aid) and mediated pathways (including energy access or technological innovation) may provide a better picture of the dynamics involved. Temporal changes and cross-regional comparisons that are longitudinal in nature would give more delicate information on the contextual factors involved in energy transitions. Interdisciplinary elements such as behavioral and psychological aspects, consumer trust, willingness to pay, and risk perceptions provide a complementary view of socio-economic models. The directions will improve the knowledge on renewable energy adoption and guide more specific and evidence-based sustainable energy transition strategies.

Volume. 4 Issue No. 3 (2025)
Online ISSN: 3006-2047
Print ISSN: 3006-2039

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Volume. 4 Issue No. 3 (2025)
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